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STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

PROCEDURES FOR COMPOSITE PAVEMENT EVALUATION

CONSTRUCTION TECHNOLOGY LABORATORIES, INC.

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16. Abstract <p>Based on the information reviewed, it is clear that most State highway agencies rely principally on the visual condition survey data to determine the condition of the composite pavements and sometimes supplement the visual condition survey data with deflection testing at location of reflection cracking.</p> <p>The current Maryland SHA procedure for evaluating a composite pavement and developing repair and rehabilitation strategies is reasonable considering the current state of the practice. Some improvements to the current SHA procedures are recommended in this report.</p>					
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DEVELOPMENT OF IMPROVED PROCEDURES FOR COMPOSITE PAVEMENT EVALUATION

1.0 INTRODUCTION

1.1 Introduction

Asphalt resurfacing is one of the more commonly used methods for concrete pavement rehabilitation. For example, in Maryland, about 36% of the state's more than 16,000 lane-miles of major roadways are composite pavements, consisting of existing portland cement concrete (PCC) pavements overlaid with hot mixed asphalt surface layer. Most composite pavements are located on roadways carrying significant traffic volumes. Thus, evaluating and maintaining/preserving the composite pavements are important activities in the overall management of Maryland's roadway system.

Similar to the procedures for evaluation of conventional PCC and asphalt pavements, the current approach used by the Maryland State Highway Administration (SHA) for evaluating composite pavements includes deflection testing, visual condition surveys, and limited amount of coring.⁽¹⁾ The deflection testing is used to assess structural capacity and subgrade support and the visual surveys are used to quantify the functional condition of the pavement and to quantify pre-overlay repair needs. Coring is used to establish layer thickness and to provide an assessment of the quality of the material in each layer. The most common distress found in Maryland's composite pavements are poor working joints in the concrete pavement underneath the asphalt surface. It is often difficult and nearly impossible to reliably identify the number of these poor joints as the asphalt concrete covers the distress. For contracting purposes, full and partial depth patches are estimated based on distress visible at the surface of the pavement which is often only an educated guess as to whether a patch should be placed or not. Due to the inaccuracies in this evaluation approach it is common to require additional or less patching during the pavement rehabilitation after the concrete surface is exposed. This is generally not cost-effective because of contact management issues.

The objective of this study is to develop an improved evaluation procedure that can more accurately assess the current overlaid concrete pavement conditions at joints and cracks, identify more suitable rehabilitation method, and better estimate type and quantity of repairs.

1.2 Composite Pavement Types

Three types of composite pavement design are used in the US. These designs are:

1. AC overlay over existing PCC (jointed or continuously reinforced) pavement. Key design/construction features include:
 - a. Some pre-overlay repairs may be performed at joints and cracks
 - b. Some crack reflection mitigation technique may be used

- c. AC overlay thickness may be “nominal” thickness, typically 3 to 4 in. depending on traffic volume.
 - d. Successive rehabilitation cycles typically involve milling the AC surface, repairing deteriorated joint and crack areas in the PCC pavement and resurfacing with AC, the AC thickness depending on traffic volume.
- 2. AC overlay over fractured jointed PCC pavement . The technique is typically referred to as the crack and seat method for plain concrete pavements and the break and seat method for reinforced concrete pavement. The underlying warrant for using this technique is to eliminate the occurrence of reflection cracking. Key design/construction features include:
 - a. Fracturing of the existing PCC pavement
 - b. Seating of the fractured pavement
 - c. Overlaying with AC. The AC overlay thickness would be larger than that for AC overlay directly over the existing PCC pavement and may range from 4 to 8 in. depending on traffic volume.
 - d. Successive rehabilitation cycles typically involve milling the AC surface and replacing with a like or slightly greater thickness depending on traffic volume.
- 3. AC overlay over rubblized PCC (jointed or continuously reinforced) pavement. Key design/construction features include:
 - a. Rubblizing of the PCC pavement
 - b. Seating of the rubblized pavement
 - c. Overlaying with AC. The AC overlay thickness would be larger than that for AC overlay over fractured PCC pavement and may range from 6 to 12 in. depending on traffic volume.
 - d. Successive rehabilitation cycles typically involve milling the AC surface and replacing with a like or slightly greater thickness depending on traffic volume.

This report is focused on the first listed design type of composite pavements, with specific attention to evaluating the condition of the composite pavement (specifically at the reflection cracking locations) for successive rehabilitation cycles. This type of composite pavement is widely used in Maryland.

2.0 REVIEW OF EVALUATION METHODS FOR COMPOSITE PAVEMENTS

2.1 Background

Even though composite pavements have been in service for many years, only traditional procedures have been used for evaluating the overall performance and specific condition of these pavements. Overall performance is typically assessed using profile testing with the performance defined in terms of a ride index, the most popular being the International Roughness Index (IRI). The IRI values together with network level visual condition survey information and other criteria (e.g., wet weather accidents) are used to flag composite pavements for rehabilitation. At the project level, the first step in developing an appropriate pavement rehabilitation strategy is better defining the specific structural and functional condition of the composite pavement. Generally, procedures used for composite pavement condition evaluation include detailed distress survey of pavement surface condition, falling weight deflectometer (FWD) deflection testing, and sometimes the use of non-destructive testing techniques (e.g., ground penetrating radar, GPR to determine asphalt layer thickness).

The traditional pavement condition procedures are used for the following purposes:

1. Deflection testing – to assess the structural characteristics of each key pavement layer as well as the overall pavement system. The composite pavement layers include the AC overlay, the PCC pavement, base/subbase, and the subgrade. For rehabilitation design, the characteristics of interest include the following:
 - a. Layer modulus of elasticity. For characterizing the base, subbase and the subgrade, the composite modulus of subgrade reaction, k , is often used. This information is obtained from FWD basin testing.
 - b. Joint load transfer effectiveness (LTE) at reflected cracks over cracks and joints in the concrete pavement. Poor LTE in the concrete pavement results in premature reflection cracking in the AC overlay and a faster rate of deterioration of the reflection cracking.
 - c. Void under the PCC pavement at joints and cracks in the PCC pavement. Presence of voids under the PCC slabs can result results in premature reflection cracking in the AC overlay and a faster rate of deterioration of the reflection cracking.
 - d. The condition of the concrete material (matrix) at the joints and cracks in the PCC pavement. Deteriorated concrete at joints and cracks can result results in premature reflection cracking in the AC overlay and a faster rate of deterioration of the reflection cracking.

Reliable procedures are available to characterize Items (a), (b), and (c) listed above. However, no practical procedures are available to reliably identify Item (d) listed above.

2. Visual Condition Survey – These surveys are used to document the type, extent and severity of distress in pavements and to assess the quality of drainage. For composite pavements, in addition to typical AC pavement type distresses, a key distress of concern is reflection cracking. Reflection cracking is the cracking that develops in the AC overlay layer over cracks and joints in the existing PCC pavement. The reflection cracking may appear prematurely soon after the overlaid pavement is opened to traffic or may develop after several years as a result of traffic loading and environmental conditioning.
3. Coring – A limited amount of coring may be undertaken to verify AC and PCC layer thickness, to visually characterize the quality of the layer materials, and to perform strength/stiffness testing, as appropriate. A limited amount of shallow borings may be done in conjunction with the coring to assess the quality of the base, subbase and the subgrade.

The basis steps for the rehabilitation of composite pavements include the following:

1. Evaluate the condition of the composite pavement. The distress of interest is typically reflection cracking and the severity of the deterioration of these cracks.
2. Review office information, including
 - a. Future traffic
 - b. Previous maintenance and repair activities carried out along the pavement section in question
3. Develop rehabilitation design strategy
 - a. Establish AC layer milling depth
 - b. Determine the thickness of new AC overlay
 - c. Identify amount of pre-overlay repair needed. These repairs typically involve repairs at joints and cracks in the PCC pavement

2.2 Review of Literature and Selected State DOT Practice

This section presents a summary of information available related to composite pavement evaluation.

Reflection Cracking Definition

Reflection cracking is simply defined as cracks in the AC overlay surface that occurs over joints and cracks in the PCC pavement. A large portion, if not all, of the reflection cracking appears at uniform spacing reflecting the uniform joint spacing of the underlying PCC pavement. The Long Term Pavement Performance (LTPP) program has adopted standard definition for reflection cracking, as illustrated in Figure 1. However, the LTPP definition is applied to joint reflection cracking only.⁽²⁾ For the purpose of this report, it is assumed that the LTPP reflection cracking definition is applicable to joint as well as PCC pavement cracking related reflection cracking.

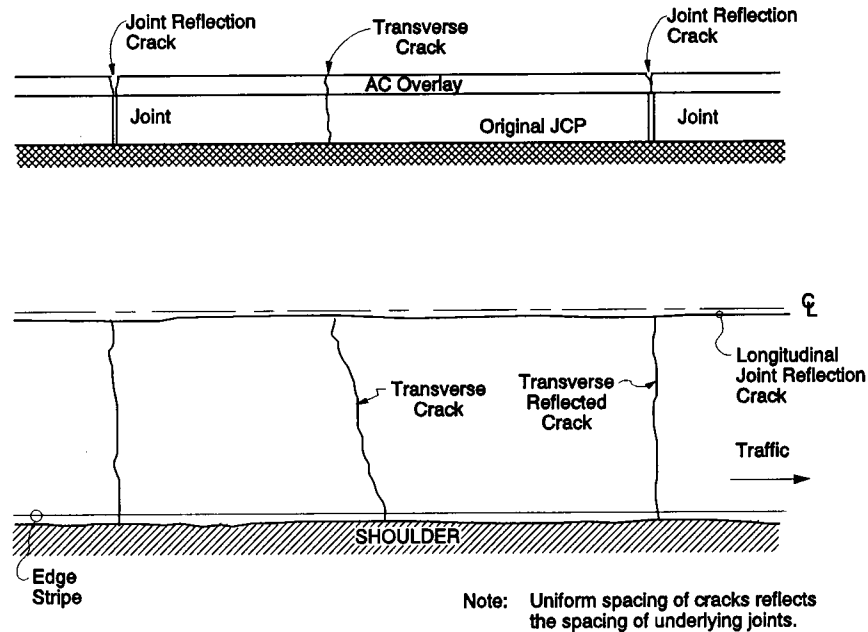


Figure 1. Illustration of Reflection Cracking ⁽²⁾

The LTPP severity levels for reflection cracking are defined as follows⁽²⁾:

- Low severity cracking – an unsealed crack with a mean width ≤ 0.25 in.; or a sealed crack with the sealant material in good condition and with a width that cannot be determined.
- Moderate severity cracking – any crack with a mean width > 0.25 in. and ≤ 0.75 in.; or any crack with a mean width ≤ 0.75 in. and adjacent low severity random cracking.
- High severity cracking - any crack with a mean width > 0.75 in.; or any crack with a mean width ≤ 0.75 in. and adjacent moderate to high severity random cracking.

An example of high severity reflection cracking is given in Figure 2. It should be noted that the LTPP definitions are based on visual observations of the surface condition of the AC overlay surface and no attempts are made to determine or establish the condition of the underlying PCC pavement at joints and cracks in the PCC pavement.



Figure 2. An Example of High Severity Cracking at Joints ⁽²⁾

AASHTO Design Guide (1993) Procedure

The evaluation and the rehabilitation design procedures for composite pavements are described in Chapter 5, Section 5.7 of the 1993 AASHTO Design Guide.⁽³⁾ The Guide identifies the following major activities:

1. Repairing deteriorated areas and making drainage improvements, if needed
2. Milling a portion of the existing AC overlay surface
3. Constructing a widening, if needed
4. Applying a tack coat
5. Placing the AC overlay, including a reflection crack control treatment, if needed.

According to the Design Guide, an AC overlay of a composite pavement would not be feasible if the following conditions exist:

1. The amount of deteriorated slab cracking and joint spalling is so great that complete removal and replacement of the existing AC surface is dictated
2. Significant deterioration of the PCC has occurred due to severe durability problems (e.g., D-cracking or reactive aggregates)
3. Vertical clearance at bridges is inadequate for required AC overlay thickness.

The Design Guide recommends that if the distress visible at the surface is predominantly a reflection of the deterioration in the underlying PCC, the pavement must be repaired through the full depth of the AC and the PCC layers. Otherwise, the distress can be expected to reflect rapidly through the new AC overlay. The Guide recommends that coring and deflection testing be conducted to thoroughly investigate the causes and extent of deterioration in the existing pavement. Section 5.7 of the Guide provides a detailed

procedure for characterizing the structural capacity of the existing composite pavement and for determining the thickness of the new AC overlay. The Guide also provides the following guidelines with respect to evaluation and treatment of deteriorated reflection cracking:

1. Reflection cracks of all severities suggest the presence of working cracks, poorly performing transverse joints, deteriorated construction joints, or failed repairs in the PCC pavement, all of which should be repaired prior to placing the new overlay.
2. Coring through selected reflection cracks should be conducted to assess the condition of the underlying PCC pavement.
3. Coring should be conducted at areas of localized distress to determine whether the distress is caused by a problem in the AC mix or deterioration in the PCC.
4. Additional coring or removal of the AC layer may be necessary to select appropriate repair boundaries.

Illinois DOT Study

In a study conducted in Illinois on AC/PCC composite pavements, distress survey and FWD deflection data were analyzed to assess structural integrity of the composite pavement systems.⁽⁴⁾ In this study, detailed analysis of the FWD deflection data was performed. Backcalculation procedures for pavement layer property estimation and guidelines for practical interpretation of these results were also developed.

Pavement distress surveys were performed to collect distress types and quantities. Distresses observed included deteriorated reflection cracking, full-depth AC patch, localized failures, rut depth, alligator cracking in wheel paths, and pumping. The primary objective of the distress survey was to obtain information required to select rehabilitation alternatives and to prepare detailed specifications, plans, and bid documents.

FWD deflection data were collected and analyzed to assess the composite pavement structural condition. In the FWD testing, four sensor positions were used. They were at the center of the loading plate, at 12, 24, and 36 in. from the center of the loading plate. A backcalculation process for estimation of PCC moduli and foundation modulus of subgrade reaction (k) was developed utilizing the AREA concept. Elastic modulus of the AC was first determined by the Asphalt Institute equation or by laboratory testing. FWD deflections measured at the center of the loading plate was then adjusted for asphalt compression. These adjusted center deflections, along with deflections measured at other three positions, were used to estimate the PCC moduli and k .

The average backcalculated PCC modulus over the length of a project was considered to be an important indicator of the pavement's structural capacity. The authors suggested some typical elastic modulus values for concrete of various types and condition, as shown in Table 1.

Table 1. Typical Concrete Moduli ⁽⁴⁾

Concrete Slab Condition	Typical Modulus, psi	Remaining Structural Life of Slab
Sound JRCPC or JPCPC	3 to 8 million	More than 5 years
Sound CRCP	2 to 8 million	More than 5 years
Concrete with significant D cracking	0.5 to 3 million	3 to 5 years
Concrete with severe D cracking	50,000 to 500,000	Less than 2 years

The study indicated that extensive D cracking at joints and cracks in an AC/PCC pavement could be diagnosed from backcalculation results. Also, the authors stated that a cumulative frequency distribution of concrete moduli is a very valuable tool in assessing the variability in values and the percent of values below a level considered critical for good quality concrete (2 million psi).

Michigan DOT Study

FWD deflection data were also collected on two roadway composite pavements in Michigan and were analyzed to evaluate their structural capacity and to determine rehabilitation strategies.⁽⁵⁾ The first project was the Nine Mile Road located in the City of Oak Park, and the second was the Military Road Project located within the Ford Motor Company research facility. For both projects, deflection data were used to determine the layer moduli and foundation support values. The backcalculated PCC moduli were then used to assess the structural condition of the PCC slabs. For pavement rehabilitation, locations where PCC moduli were less than 2 million psi were considered as areas where slab replacements and pavement repairs were needed. PCC moduli between 2 and 3 million psi indicated that repairs might be needed in these areas.

Ontario Studies

In 1997, falling weight deflectometer (FWD) testing was conducted on Highway 401, which was a composite pavement consisting of AC over PCC, located in Ontario, Canada.⁽⁶⁾ Both deflection basin testing and load transfer across joints and cracks were performed. Results from the basin testing were used to backcalculate the layer properties and load transfer efficiency was determined using joint/crack test results. Since the deflection testing was conducted on top of the asphalt surface and the measured deflection under the FWD loading plate may include the compression in the AC layer,

which is a deviation from the slab theory typically used for PCC pavement analysis, the deflection measured under the loading plate was excluded in backcalculation of the layer properties. For the same reason, the testing layout for the load transfer efficiency (LTE) determination, as shown in Figure 3, was also different from the layout typically used.

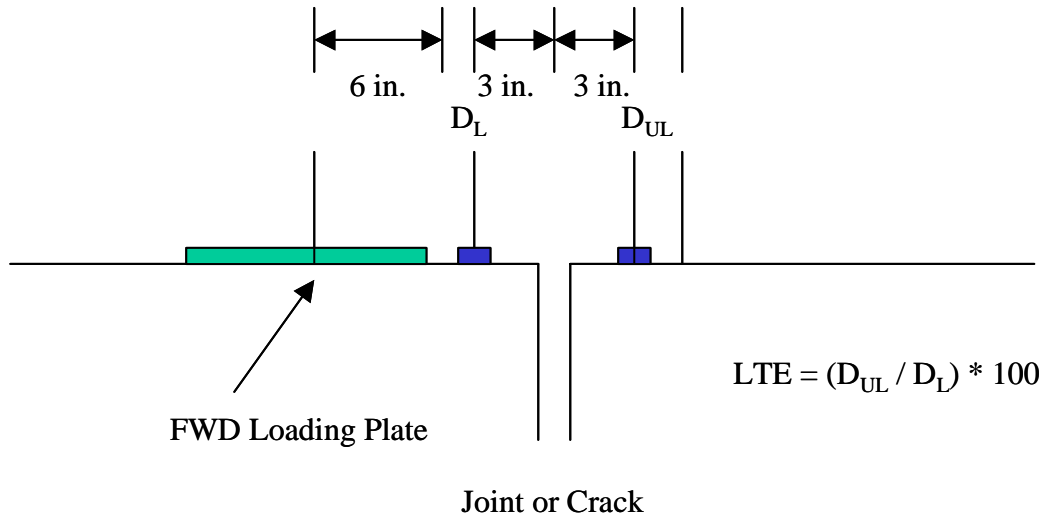


Figure 3. Layout of Load Transfer FWD Testing on Highway 401

Analysis of the deflection data showed large variation in the calculated LTE. However, the average LTE values decreased with increasing AC reflection crack severity. It was noted by the investigators that the severity of the reflection cracking of a joint or crack was found to be an excellent indicator of underlying PCC joint or crack condition. The higher the reflection crack severity, the lower the expected joint or load LTE.

Another in-depth evaluation of the composite pavements on Highway 401 was conducted in 2000 and 2001.⁽⁷⁾ The evaluation was performed to assess the condition of the underlying concrete for the 29-mile composite pavement section. This section of Highway 401 was originally built in 1950's as a four-lane divided highway with a PCC slab of 9 in. thickness, a 4 in. thick granular base and a 5 in. thick granular subbase. Many rehabilitation activities, including AC overlays, have been performed on this pavement over the years. The in-service pavements had an AC overlay layer of about 9 in. thickness.

For this investigation, 16 pavement sections, each 160 ft in length in the driving lane, were selected for detailed evaluation. The detailed evaluation included the following

1. A detailed PCC surface condition survey after removing the AC overlay
2. FWD load testing on joints and cracks
3. Asphalt and concrete pavement coring

4. Test pits at the pavement edge (at joints)
5. Laboratory testing of recovered AC and PCC samples.

The primary distresses on this pavement were joint and crack faulting, joint and crack spalling and mid-slab transverse cracking. Measured LTE (on PCC surface) were generally consistent with the overall visual condition of the concrete slabs. One important result derived was that the condition of the underlying PCC did not correlate well with the visual condition of the asphalt surface.

The rehabilitation methodology currently used by the Ministry of Transportation, Ontario (MTO) for conventional composite pavement with thinner AC layer (about 4 in.) includes the following:

1. Removing all AC overlay surface during the initial stage of construction
2. Conducting condition surveys on the exposed PCC surface
3. Conducting FWD deflection testing at joints and cracks in the exposed PCC pavement
4. Modifying the decision matrices for concrete pavement restoration (CPR)
5. Performing the CPR activities according to the revised plan
6. Resurfacing the pavement with 2 to 3 lifts of AC.

In summary, the repair quantities are first estimated based on the visual condition surveys of the AC surface and then revised based on the results of condition survey and deflection testing conducted on the exposed PCC surface after AC removal.

Adjacent State DOT Practices

A review was conducted to review current composite pavement evaluation methods used by other states. Discussions were conducted with Mr. Nick Vitillo of New Jersey Department of Transportation (DOT), Mr. Dave Kilpatrick of Connecticut DOT and Mr. Wes Yang of New York State DOT. The New Jersey DOT is currently selecting and designing its composite pavement rehabilitation strategy and estimating repair quantities solely based on condition surveys conducted on AC surfaces. FWD deflection testing on AC surface across reflection cracks has only been occasionally used. In this case, LTE of less than 70% is considered unacceptable and the affected joints and crack areas are targeted for repair. Similarly, the Connecticut DOT and New York State DOT use only the distress surveys on AC surfaces as the criteria for composite pavement evaluation. All three states do not have special pavement evaluation specifications just for composite pavements.

GPR Based Studies

Attempts were also made in New York, Connecticut, and Illinois to use Ground Penetrating Radar (GPR) for composite pavement evaluation.⁽⁸⁾ The three composite pavements were located on interstate highway, I-495 near New York City, I-95 in New Haven, and I-90 in Chicago. The I-495 was a nine-mile section in Nassau County, New York. The I-95 project was a four-mile section in New Haven, East Haven, and

Branford, Connecticut, and the I-90 project involved a 15-mile section in Chicago, Illinois. Typical pavement structures consisted of 3 to 5 in. of asphalt over 8 to 10 in. of PCC.

The main objective of these projects was to determine depth of asphalt layer and condition of the concrete near the interface. The GPR equipment generates short pulses of electromagnetic energy, which penetrate into the pavement structure and reflect back at the layer interfaces. The amplitude and time of these reflected waves are used to determine the thickness and properties of the pavement layers. To evaluate concrete condition, data collected were analyzed to identify areas where the dielectric constant differed significantly from the average value. These were the areas with either high or low moisture content, indicating either excessive moisture infiltration or high void content.

2.3 Framework for Composite Pavement Evaluation

To adequately evaluate in-service composite pavements, the evaluation should include a visual survey, a structural evaluation, a functional evaluation, and a drainage evaluation.⁽⁹⁾ A distress survey starts the process of identifying pavements needing repair and estimating the repair quantities. Typical distresses on AC/PCC composite pavements are reflection cracking, localized failures at joints and cracks due to D-cracking or ASR in the PCC, rutting, stripping, and weathering.

A structural evaluation is performed to determine the composite pavement's structural integrity. Non-destructive deflection testing complemented by limited amount of destructive testing (pavement coring and laboratory testing) is the most effective method for conducting the structural evaluation of composite pavements. The final results of the structural evaluation are elastic modulus of each layer, modulus of subgrade reaction (k), and load transfer capabilities at joints and cracks. Generally, the load transfer capability is characterized by load transfer efficiency (LTE), which is defined as the deflection measured at the unloaded side divided by that measured at the loaded side, expressed in percentage. A joint or crack with perfect load transfer has an LTE of 100 percent, while a joint/crack with no load transfer capabilities has a LTE value of 0 percent. A commonly used rating scale is as follows:

<u>Joint/Crack LTE, %</u>	<u>LTE Rating</u>
>70	Good
50 to 70	Fair
<50	Poor

A functional evaluation is performed to assess the pavement surface conditions in terms of its ability to provide comfortable and safe rides to the users. Surface friction and roughness are the two major components of a functional evaluation. While roughness is related to the ride quality, the friction is required to provide safe ride.

The last component of the composite pavement evaluation is the drainage evaluation. The existence of trapped water in the pavement system can cause water related distresses, such as D-cracking, localized failures, pumping, and voids under the slabs. The drainage survey can be conducted in conjunction with the visual distress survey. The effectiveness of the existing drainage should be tested, either during a rainfall or during man-made condition. The following items need to be assessed during a drainage survey:

- Are the ditches clear of standing water?
- Are the ditch lines and pavement edges free from weed growth?
- Is there water in the joints or cracks after rain?
- Is there evidence of pumping during and after a rain?
- If subdrainage is used, are the outlets known, clear of debris, and set at the proper elevation?
- Are inlets clear and set at proper elevation?
- Are the joint and crack sealants in good condition?

3.0 CURRENT MARYLAND SHA PROCEDURE FOR COMPOSITE PAVEMENT EVALUATION

3.1 Introduction

Although composite pavement systems (concrete pavements overlaid with AC surface) represent a large portion of the existing highway pavements in the US, especially along heavily trafficked interstate and other major highways, no significant improvements have been made in the technology to better evaluate the condition of the composite pavements for successive rehabilitation. The most common procedure for composite pavement evaluation is based on visual condition survey of AC surface. FWD testing is also used, but not routinely. Studies did suggest the use of FWD deflection data for assessing the existing PCC pavement condition underneath the AC surface. These studies emphasized the use of basin deflection data for estimating concrete elastic modulus as an indicator of the existing concrete condition. In Maryland, the most severe and frequently encountered problem on composite pavements is not related concrete materials (e.g. low modulus of elasticity); rather, it relates to deteriorated reflection cracking above concrete pavement joints or cracks. This section describes the evaluation process currently used by Maryland SHA.

3.2 The Process

The current MDSHA procedure for composite pavement evaluation is summarized from the MDSHA Pavement Division Design Guide⁽¹⁰⁾, which was under development and revision at the time of this study (Year 2002), and incorporates additional feedback provided by MDSHA personnel. In general, once a project is initiated, the current MDSHA composite pavement evaluation procedure consists of the following four steps:

1. Visual Condition Survey

A visual condition survey of the existing pavement is conducted to document the overall condition of the pavement and to identify predominant distress types in the pavement. The survey results aid in the rehabilitation design process by providing necessary information for determination of the most effective rehabilitation alternatives. A typical visual condition survey consists of the following steps:

- Delineate uniform pavement sections with similar pavement type, traffic volume and pattern, overall conditions, etc.
- Determine evaluation sample length and sampling rate for each uniform section.
- Conduct a detailed survey by walking along the highway pavement and recording the observed distress types and severities.
- Mark coring locations, if necessary.
- Input and analyze data using the PAVER procedure and compute the Pavement Condition Index (PCI) to characterize the overall condition of the pavement.
- Conduct a quality control check.

2. FWD Testing

FWD deflection testing is conducted to collect deflection data. Three types of deflection tests are generally performed in Maryland, the basin testing, the joint or crack testing, and corner testing. Deflection data obtained from the basin testing for a PCC pavement are used to estimate pavement layer properties, foundation support condition, and to assess the overall structural capacity of the pavement. For composite pavement evaluation, the primary use of the basin testing is to establish the hot mixes asphalt (HMA) compression or bending factor.

The joint/crack testing is performed to evaluate the load transfer capability of the joints/cracks in composite pavement. Corner testing is used to assess the performance of existing corners and to determine the presence of voids under the corners of the slabs. However, corner testing is not routinely performed for composite pavements.

The joint/crack deflection testing is particularly important in composite pavement evaluation since the reflection cracking is one of the most dominant distresses observed in composite pavement in Maryland. Repair strategy is therefore largely dictated by the condition of the underlying joints or cracks. Typically joint/crack testing is performed by placing the loading plate on one side of the joint/crack with two sensors, each positioned on one side of the joint/crack. The two sensors are positioned 12 in. from center of the loading plate on each side of the joint/crack (Figure 4). On average, one day of testing is generally required for one project. Normally, 25 percent of joints/crack are subjected to FWD testing.

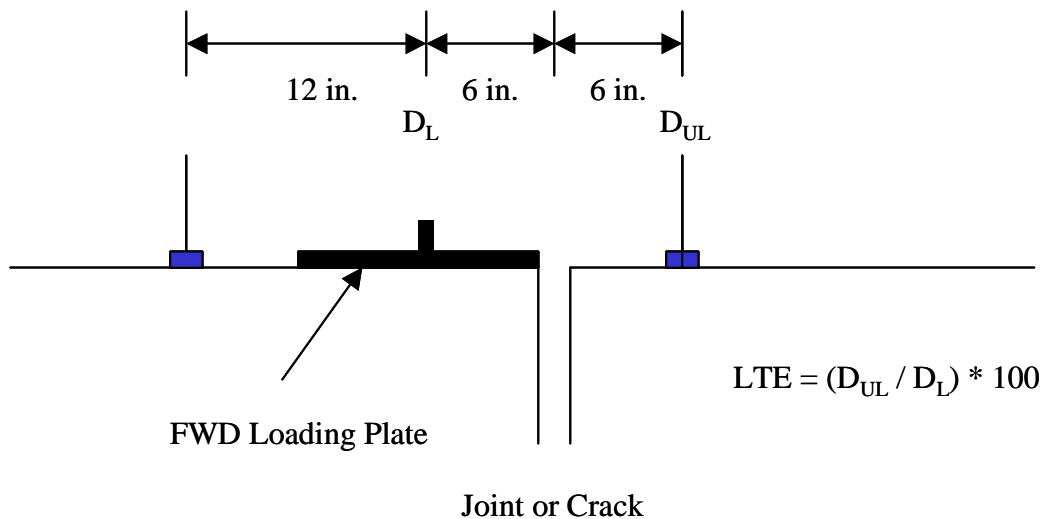


Figure 4. Configuration of Load Transfer Testing in Maryland

For composite pavement, results from the condition survey and FWD joint/crack testing are used to determine the repair methods to be used for mitigating reflection cracking. Criteria for selecting rehabilitation methods include the AC layer thickness, depth of

milling of existing AC overlay, severity of the reflection crack, and the LTE. Table 2 shows the selection criteria and the appropriate treatment methods.

Table 2. Criteria for Rehabilitation Method Selection

LTE, %	Reflection Cracking Severity	Repair Type		
		No Milling Considered	1 to 2 in. Milling Considered	
			AC Thickness > 6 in.	AC Thickness < 6 in.
>70 (Good)	Low	None	None	None
	Medium	Partial Depth	None	Partial Depth
	High	Partial Depth	Partial Depth	Partial Depth
<70 (Poor)	Low	None	None	None
	Medium	Partial Depth	Partial Depth	Full
	High	Full	Full	Full

3. Pavement Coring

Maryland SHA typically requires one core to be obtained for every 200-ft section of a two-lane highway. Locations of pavement coring are generally determined and marked by engineers during the PCI condition surveys. The AC and PCC cores are subjected to laboratory testing to provide information required for pavement rehabilitation design. The information obtained may include AC and PCC thickness, AC and PCC strength and stiffness, and the AC/PCC interface condition. In some cases, borings may be extended into the base, subbase, and subgrade to obtain samples of materials from the underlying layers. The materials and thickness information is used to verify data obtained from construction records and for conducting pavement rehabilitation design. The layer thickness is a very important parameter in the back-calculation procedures for determination of pavement layer properties using the FWD deflection data.

4. Patching Survey

Patching survey in the pavement rehabilitation design process is performed to identify type (full depth or partial depth) and location of patches, and to establish material quantities required for patching. The patching survey is conducted by walking along the entire project length to obtain detailed information for estimation of patching locations and required quantities. The entire pavement width, including the traffic lanes, shoulders, ramps, and intersections is evaluated. The collected information during the patching survey includes the following:

- Patching lane
- Location of patch within lane
- Starting and ending points of patch
- Distress type and severity of existing patches

- Patch size

A quality control (QC) check is also conducted by conducting the same patching surveys on randomly selected 5 percent of the pavements previously surveyed. An independent surveyor conducts the QC survey. If the difference in patching quantities and locations between the original survey and the QC survey is greater than 3 percent of the QC areas, the patching survey is re-evaluated.

5. *Repair/Rehabilitation Strategy*

The overall evaluation and repair/rehabilitation process used by Maryland SHA involves the following steps:

1. Visual condition survey
2. LTE testing, as necessary
3. Consideration of existing AC overlay
 - i. Thickness
 - ii. Age
 - iii. Material quality
4. Consideration of previous repairs and milling

Based on the four items listed above, decisions are made with respect to type of patching (partial depth in the AC layer only or full depth PCC patches), depth of milling (full depth milling if AC thickness is ≤ 3 in., up to 2 in. milling if AC thickness is greater than 3 in.). Additional considerations in selecting the final repair/rehabilitation strategy include the following:

1. Traffic volume
2. If full depth AC milling is done, can the exposed PCC surface carry the traffic at acceptable speeds before the new AC overlay is place?

3.3 Summary

The current MDSHA procedure for evaluating the condition of composite pavements and for developing repair and rehabilitation strategies is fairly routine given the state of the practice. This procedure results in a best estimate for pre-overlay repair type and quantities that are used for contracting purposes. Repair type and quantities are then adjusted based on the condition of the pavement (particularly the PCC pavement) after the designated amount of milling is done.

4.0 DEVELOPMENT OF IMPROVED EVALUATION PROCEDURE FOR COMPOSITE PAVEMENTS

4.1 Assessment of MDSHA Current Evaluation Process

From the literature review and the discussions with several State DOT personnel, it is clear that no definitive procedures exist to reliably assess the condition of the underlying PCC at the location of medium to high severity reflection cracking. Most states DOT's are using data obtained from condition survey on the AC surface as the basis for determining the required composite pavement rehabilitation methods. However, as the Ontario study on Highway 401 has indicated, the condition at the AC surface may not be indicative of the condition of the underlying concrete slabs. It should be noted that the thickness of the AC overlay along Highway 401 was about 9 in. Conventional composite pavement with a thinner AC layer (generally equal to or less than 4 in.) may behave differently. Some limitations of the current MDSHA procedure for composite pavement evaluation include the following:

- The condition survey conducted under current evaluation procedure utilizes the PCI index. However, since the single most important distress observed on Maryland's composite pavements is reflection cracking, the condition of the reflection cracking (severity, faulting, crack width, etc.) should be evaluated separately and categorized separately and not integrated within an overall condition index.
- There is typically little coordination between personnel conducting condition surveys and FWD testing. LTE testing is performed randomly at locations selected by the FWD operator. The FWD testing locations should be marked by engineers based on the results of the condition surveys.
- As discussed previously, the condition and LTE obtained at the AC surface may not correlate well with the condition of the underlying concrete. There is a need to develop correlations between the condition of the reflection cracking and LTE obtained at the AC surface with the actual condition of the concrete underneath.
- Current sensor configuration for LTE testing will require the adjustment for AC compression at the center of the loading plate. A different sensor configuration, such as the one used in an earlier Ontario study (Figure 3), should be evaluated.

4.2 Potential Techniques for Reliably Determining Underlying PCC Condition

As discussed previously, both visual condition survey and FWD testing have their limitations with respect to reliably identifying the condition of underlying concrete at reflection cracking locations. However, used properly in combination, the results from the condition survey supplemented by deflection testing results can provide a fairly reliable estimate of the extent of deterioration of the underlying PCC. The use of NDT techniques was explored. The NDT techniques considered were:

1. Ground penetrating radar (GPR)

2. Impact echo technique (IE)
3. Impulse response technique (IR)

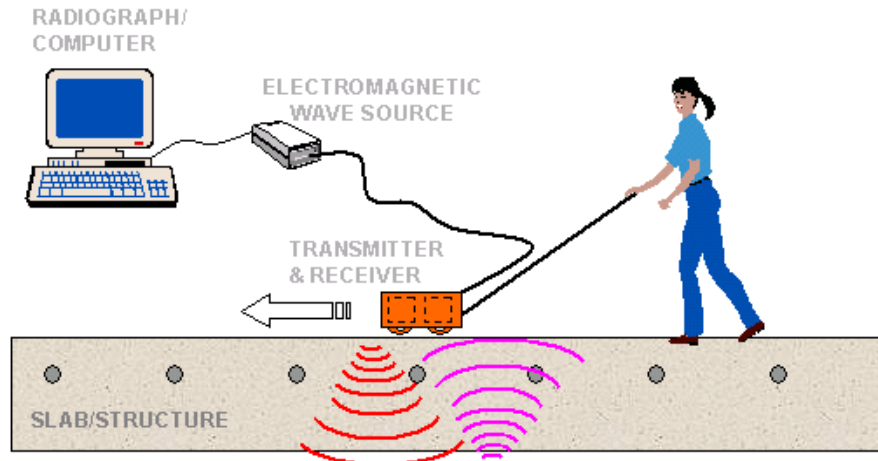


Figure 5. The GPR Test Process ⁽¹¹⁾

The use of the GPR technique was discussed earlier in the report. GPR is a nondestructive testing technique which involves using electromagnetic waves to assess internal characteristics of a material. A radar pulse is composed of electromagnetic waves, typically transmitted at microwave frequencies and very short in duration. Electromagnetic waves are transmitted and received by antenna. The receiving antenna collects the energy reflected from dielectric interfaces between materials of differing dielectric properties. The travel times of the waves are related to the dielectric constant of the material. The GPR technique, illustrated in Figure 5, is routinely used to locate steel or other reinforcement in concrete and to determine the location of internal flaws in concrete. The GPR equipment is portable. The use of this technique requires an expert GPR operator and it is expensive to use. For composite pavement applications, the GPR technique has not been very successful.

The Impact Echo (IE) technique uses a surface impactor to generate L-waves in the material to be tested. As illustrated in Figure 6, the L-waves are reflected at discontinuities or interfaces. The reflected waves set up resonance condition having a characteristic frequency. The resonant frequency (at the peak) is related to distance to reflector and wave velocity. The IE test is relatively simple test to performed using commercially available test equipment. IE testing is effective for detecting delamination and slab depth. Operator experience is needed for IE test data interpretation. The IE test has not been effective on composite pavements.

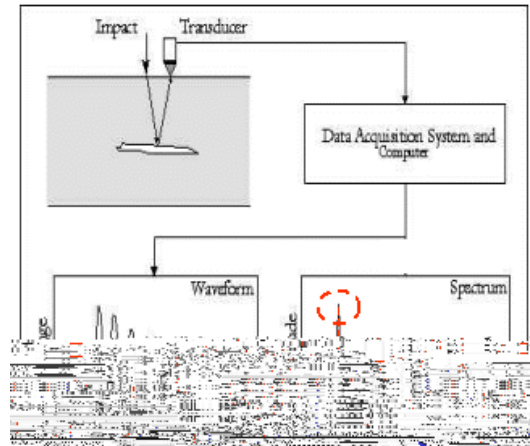


Figure 6. Schematic of Impact Echo Test ⁽¹¹⁾

In the Impulse Response technique, low strain impact on structural element generates compression stress wave (as in Impact-Echo method, but lower frequency band [0-800 Hz] & much greater force input). The impact force is measured by load cell. The response to impact is measured by a velocity transducer (geophone) in time domain. The technique is illustrated in Figure 7. The test data are used to determine the structure's mobility index as a function of frequency. Similar to the IE method, the IR method requires an experienced operator for data interpretation. This method has not been applied to evaluation of composite pavements.

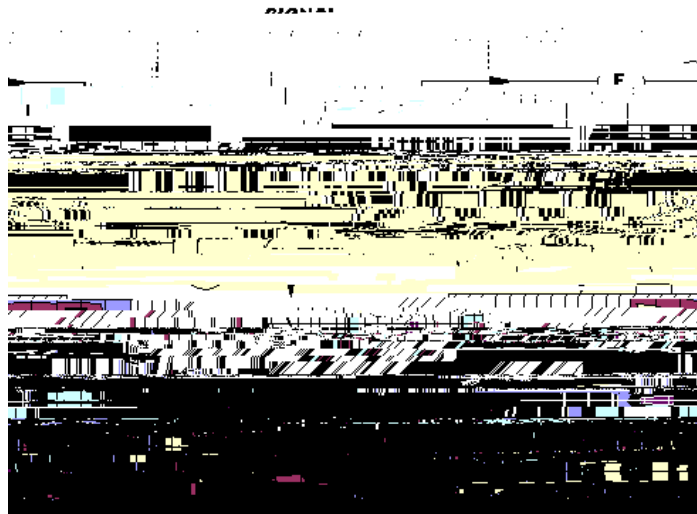


Figure 7. Schematic of Impulse Response Test ⁽¹¹⁾

After a review of the applications of the above discussed NDT procedures and discussions with experts in the use of these techniques, it was determined that the use of these techniques on a routine basis for routine evaluation of composite pavements cannot be considered feasible because of the current state of the development of these techniques, the need for an expert operator, and the cost.

